COURSE: Prescribed Fire Planning and Implementation

TOPIC: Prescription Development (Unit 4)

I. Objectives

A. Discuss prescribed fire prescription variables and relate them to the accomplishment of prescribed fire objectives.

B. Discuss how the assumptions and limitations in the fire spread model are related to a prescribed fire situation.

C. Demonstrate how BEHAVE PLUS may be used to develop prescribed fire prescriptions.

II. Introduction

Prescribed fire can be expensive, and with a limited number of days to burn (often called the burn window), a well-defined prescription is critical to success.

Poorly planned and conducted prescribed fires can result in grave consequences, including the loss of property and lives. Skillful planning can prevent or significantly reduce the risk of a prescribed fire disaster.

Burning prescriptions should be designed to meet specific objectives on the unit and adjacent land. Prescription variables include, but are not limited to: fire behavior, fuels, vegetation, soil, weather, time, National Fire Danger Rating System variables, and firing technique. Not all variables apply to every planned prescribed fire.

III. Fire Behavior Variables

A. Rate of Spread (ROS) - The relative activity of a fire in extending its horizontal dimensions, usually measured in chains/hour. ROS is important inside a unit as an estimator of relative ease of fire spread throughout the planned area, and may be more important outside the unit when contingency planning is critical to the burn.

B. Fireline Intensity (I_B) - The rate of heat release per unit width of the flaming front per unit time. Usually measured in btu/ft/sec. Fireline intensity is useful in planning for control forces and their ability to attack a fire front. As an example, hand crews can be used to direct attack a flaming front if the intensity is less than 100 btu's/ft/sec. Fireline intensity is difficult to measure, but can be closely approximated because of its strong correlation with flame length.

C. Flame Length (FL) - Flame length, which is observable, is well correlated with fireline intensity. A 4-foot flame length correlates with I_B of 100 btu's/ft/sec. This is usually used as the upper limit for direct attack of a free burning fire with a hand crew and hand tools. Flame length has many uses in prescribed fire planning.

IV. Fuel Variables

A. Dead Fuel Moisture Content (MC) - The moisture content of dead fuel expressed as a percent of oven-dried weight of the fuel. Dead fuel moisture content is expressed by fuel size class and determines how each class of fuel will consume during flaming combustion.

NOTE: 1 HR FUEL MOISTURE = f(temperature, RH, slope, aspect, time of year, time of day)

B. Duff Moisture Content (DMC) - The moisture content of duff expressed as a percent of oven-dried weight of the duff. Duff moisture content influences how much duff will consume in smoldering or glowing combustion.

V. Vegetation Variables

A. Live Fuel Moisture Content - The moisture content of live fuels expressed as a percent of oven-dried weight of the fuel. Live fuel moisture content determines the effect of live fuels on fire behavior.

B. One of the most difficult vegetation variables to use in the context of fire behavior prediction as it relates to the meeting of objectives is that of the vegetative stage of development. Most species of plants are more or less susceptible to fire, depending upon the time of year and their growth stage. A given species may be most susceptible to fire during the spring of the year when new foliage is present and enough dead fuel from the last growing season is also present to carry fire through the new growth. Other species may be susceptible to fire damage during the latter stages of growth when fire may impair the plant's ability to recover the next spring.

VI. Weather Variables

A. Temperature - Temperature influences how fast fuels dry, and also their final MC. Temperature also influences scorch height and probability of ignition.

B. Relative Humidity (RH) - Relative humidity influences fuel moisture content, especially of 1 HR and 10 HR fuels.

C. Wind - may be the most important fire behavior variable, due to its effect on fire behavior outputs. Influences scorch height and spotting distance.

VII. Time Variables

A. Seasonal - Season of the year influences plant condition, sprouting, seed source, and potential insect attack. Burning during various seasons can significantly affect plant response.

B. Diurnal - Daily changes in temperature, relative humidity, and wind speed can significantly affect fire behavior and first order effects.

VIII. National Fire Danger Rating System (NFDRS)

A. Energy Release Component (ERC) - ERC is a number related to the heat release rate within the flaming front of a moving fire.

IX. Firing Techniques

A. Firing techniques affect the quantity and quality of first order fire effects. The proper selection of firing technique is important when other variables dictate a modification of the burning plan. The prescribed fire burn boss must sometimes attempt to meet objectives based upon knowledge of plant response to various types of fires. A headfire or a strip headfire may result in lots of flame length and a more rapid rate of spread where a backing fire may result in lesser I_B, but due to longer duration and more fuel consumption in flaming combustion provide results more responsive to objectives.

X. The Prescription Design Process

For the purposes of prescribed fire planning, the fire "prescription" is not defined so much by the inputs into a fire spread model (temperature, relative humidity, wind speed, etc.) as it is by the outputs derived from the inputs (rate of spread, flame length, fireline intensity, scorch height, etc).

A. The prescription design process actually began with the setting of objectives. Burn objectives and acceptable range of results define the limits under which we can conduct a prescribed fire. These limits vary from burn to burn, and a prescribed fire manager/burn boss/prescribed fire planner must be able to translate objectives from different areas into definable fire behavior outputs.

B. One of the objectives of this unit is to help you understand how to design a prescription using the BEHAVE PLUS fire behavior prediction system. Before we begin this, we need to review some of the assumptions and limitations of the fire spread model used in BEHAVE PLUS as explained by Dr. Richard Rothermel in "How to Predict the Spread and Intensity of Forest and Range Fires."

> "The fire model is primarily intended to describe a flame front and advancing steadily in surface fuels within 6 feet of and contiguous to the ground. Typical of such fuels are dead grasses, needle litter, shrubs, and dead and down limb wood, and logging slash. These are the fuels in which fires start and make their initial runs and in which direct attack is usually made.
>
> The methods and model in this manual do not apply to smoldering combustion such as occurs in tightly packed litter, duff, or rotten wood.
>
> Severe fire behavior such as crowning, spotting, and fire whirls is not predicted by the fire model. The onset of severe fire behavior, however, can often be predicted from surface fire intensity as will be explained.
>
> Short-range firebrands may be blown ahead of the fire where they ignite fuels and increase the rate of fire spread. This mechanism is not accounted for, but the deficiency does not appear to affect the prediction of fire behavior. Short-range firebrands must ignite the fuel and start a new fire front before the fire overruns that position or the spotting will not be significant in increasing spread rate. In many cases, the main fire does overrun the potential spot fires. Further, the model assumes fuels are uniform and continuous. Short-range spotting can actually compensate for the discontinuous nature of some fuels, giving extended usefulness of the model.
>
> Although the original model was developed for uniform continuous fuels, subsequent research on nonuniform fuels and the introduction of the two-fuel model concept permit some nonuniformity to be considered.
>
> The methods in this manual describe the behavior at the head of the fire where the fine fuels are assumed to carry the fire. Backing fires can also be described in some cases. The burnout of fuels, usually large fuels and tightly packed litter, behind the fire front is not described.

Only the foliage and fine stems of living plants are considered fuels. When moisture content is high, such plants can dampen fire spread. When moisture content drops below a critical level, however, living plants can increase the rate of fire spread. This is accounted for by the fire model.

It is assumed that the fire has spread far enough so that it is no longer affected by the source of ignition. The system is therefore of limited usefulness in predicting behavior of prescribed fires, where the pattern of ignition is often used to control fire behavior. Nevertheless, the model is often used to plan prescribed fires by assessing the fire potential both inside and outside the proposed burn area."

C. As Dr. Rothermel states in the last paragraph, the model is of limited usefulness in predicting behavior of prescribed fires since the ignition pattern used in most prescribed fires influences fire behavior inside the unit. However, the outputs obtained from BEHAVE PLUS do have value inside the unit as they are indicators of potential fire behavior under a given set of environmental conditions. As an example, if in order to meet objectives, a flame length of 3-4 feet is necessary, and the BEHAVE PLUS outputs show a maximum flame length of 2.5 feet, the objectives cannot be met. If BEHAVE PLUS outputs show a maximum flame length of 6 feet, then the ignition pattern can be used to produce necessary flame lengths, and/or a specific set of environmental conditions can be used to meet objectives.

D. Once a prescription has been designed for fire behavior inside the burn unit, the prescription (or the inputs) have to be tested outside the unit. This is critical to the conduct of the burn as we shall discuss during the contingency planning portion of the class. Fire behavior outside the unit (as in an escape) may create more problems than can be handled with available resources. Contingency planning will be discussed in Unit 7.

XI. Fire Behavior Prediction

A. The process of fire behavior prediction is basically a simple process. A few inputs are run through a processor which calculates outputs. Necessary inputs are: (1) NFFL fuel model, (2) dead fuel moisture, (3) live fuel moisture, (4) slope, and (5) wind speed and direction.

B. In a wildfire situation, a Fire Behavior Analyst gathers available environmental data, inputs the data into the processor, and uses the outputs to predict fire behavior for a time period. Outputs are used primarily to assign resources to the wildfire in order to contain and control it.

C. In a prescribed fire situation, a fire behavior planner determines which fire behavior outputs are important to meeting stated objectives and the magnitude of the outputs. Working in a reverse situation, the planner then calculates a range of environmental conditions which will produce desired outputs. The fire behavior prescription window then becomes the **combination** of environmental data which will produce outputs of appropriate magnitude. The prescription window may be relatively "wide" if only one or two objectives must be met, and relatively "narrow" if numerous objectives must be met.

<u>Examples</u>:

<u>Objective</u>: Treat at least 70% of the unit with fire.

This can be a valid objective. Many units do not have to have fire cover 100% of the ground. Also, due to a lack of fuels continuity, it may be difficult to cover all of the area unless special lighting techniques are employed.

Which fire behavior output will help predict that the objective can be met? It can be argued that none of the outputs really will answer this question. However, rate of spread does indicate somewhat that under given conditions, a fire will (or will not) spread well. No interpretations of spread rates will be attempted here.

<u>Objective</u>: Reduce 0-1" fuel loads (1 hr. & 10 hr.) by at least 70%.

This objective may be very similar to the one presented above. Under "normal dry" conditions, most 1 hr. and 10 hr. fuels will consume in the flaming front. Therefore, it may only be necessary to cover 70% of the unit with fire.

<u>Objective</u>: Retain 80% of 100 hr. and 1,000 hr. fuels.

Accomplishment of this objective requires fuel moisture in these fuels to be relatively high - maybe 15% - 25%. Fuel moisture of less than 10% will result in consumption of these fuels in smoldering combustion. This has the potential of severely impacting the site since the duration of heat is long.

Objective: Kill at least 70% of understory trees less than 20' tall.

Mortality and scorch modules will assist in the planning process. Years of experience or well-documented case examples provide insight into the effect of fire on tree mortality. Mortality, as predicted by BEHAVE PLUS, varies by bark thickness and volume of crown scorch. Even with no crown scorch, significant mortality is predicted at small bark thickness. As bark becomes thicker, more crown scorch is needed to result in mortality.

Modules: MORTALITY

Description		Mortality Unit 4

Fuel/Vegetation

Tree Height	ft	20
Crown Ratio		.6
Mortality Tree Species		PINPON
Bark Thickness	in	0.1, 0.2, 0.3, 0.4, 0.5, 0.6

Fire

Scorch Height	ft	8, 10, 12, 14, 16, 18, 20

Run Options

No run options selected.

Output Variables

Probability of Mortality (%)

Notes

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Probability of Mortality (%)

Bark Thickness in	Scorch Height ft 8	10	12	14	16	18	20
0.1	79	86	95	99	100	100	100
0.2	69	79	92	98	99	100	100
0.3	58	69	88	96	99	100	100
0.4	46	59	82	95	98	99	99
0.5	37	49	75	92	98	99	99
0.6	29	40	68	89	97	98	99

If the bark thickness of 20' trees is 0.5" and the crown ratio is 0.6, about 12' of scorch height is necessary to meet 70% mortality objectives. Actually, scorch height can be 12'-20' (or more) depending on other objectives.

Scorch height is predicted as a function of flame length and midflame wind speed.

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Modules: SCORCH

Description		Scorch Unit 4

Weather

Midflame Wind Speed	mi/h	2.0, 4.0, 6.0, 8.0, 10.0, 12.0, 14.0
Air Temperature	oF	77

Fire

Flame Length	ft	1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0

Run Options

No run options selected.

Output Variables

Scorch Height (ft)

Notes

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Scorch Unit 4
Scorch Height (ft)

Midflame Wind Speed mi/h	Flame Length ft 1.0	2.0	3.0	4.0	5.0	6.0	7.0
2.0	2	8	15	23	32	42	53
4.0	1	5	11	19	28	39	49
6.0	1	3	7	14	22	32	43
8.0	0	2	5	10	17	25	35
10.0	0	1	4	8	13	20	28
12.0	0	1	3	6	10	16	23
14.0	0	1	2	5	8	13	19

At 77 degrees Fahrenheit, we need at least a 3' flame length to get 12' scorch. This only occurs at wind speeds less than 4 mph. At wind speeds greater than 4 mph, too much air is mixed with the rising heated air and a lethal temperature of 140 degrees at the base of the crown is not reached. At a flame length of 4', the wind speed needs to be less than 5 mph, at a flame length of 5.0', wind speed needs to be less than 11.0 mph, etc.

Objective: Don't kill overstory. Mortality levels up to 10% are acceptable.

This is the reverse of the previous objective. We again look at mortality, but this time searching for those combinations of bark thickness and scorch height that will keep mortality less than 10%. The primary variable is bark thickness. If bark thickness is greater than 1", then mortality should fit into the objective.

Modules: MORTALITY

Description		Mortality Unit 4

Fuel/Vegetation

Tree Height	ft	60
Crown Ratio		.5
Mortality Tree Species		PINPON
Bark Thickness	in	0.6, 0.8, 1.0, 1.2, 1.4, 1.6

Fire

Scorch Height	ft	8, 10, 12, 14, 16, 18, 20

Run Options

No run options selected.

Output Variables

Probability of Mortality (%)

Notes

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Mortality Unit 4
Probability of Mortality (%)

Scorch Height ft	Bark Thickness in 0.6	0.8	1.0	1.2	1.4	1.6
8	29	18	11	8	6	4
10	29	18	11	8	6	4
12	29	18	11	8	6	4
14	29	18	11	8	6	4
16	29	18	11	8	6	4
18	29	18	11	8	6	4
20	29	18	11	8	6	4

II. Prescription Windows

A. Prescription windows are the range of environmental conditions that produce desired fire behavior and subsequently, first order effects. A prescription window may appear to be "wide" as it is displayed within a prescribed fire plan, but it may really be very narrow if it is tied to specific objectives.

Assume: Fuel Model 2 - Timber (Grass and Understory) Objective/Acceptable Range of Results requires that the flame length/fireline intensity be less than 11 feet/1000 btu/ft/sec. At this point, it doesn't matter what the actual objective was, just that in order to meet the objective a flame length of less than 11 feet is required.

In order to determine the prescription window, the prescribed fire planner must first determine the range of environmental conditions that produce flame lengths of 11 feet or less. This requires inputting a range of 1-hour fuel moisture and wind speeds into the BEHAVE PLUS system.

Modules: SURFACE

Description		Prescription Windows

Fuel/Vegetation

Fuel Model		2

Fuel Moisture

1-h Moisture	%	3, 5, 7, 9, 11, 13, 15
10-h Moisture	%	10
100-h Moisture	%	15
Live Herbaceous Moisture	%	100
Live Woody Moisture	%	

Weather

Midflame Wind Speed	mi/h	2.0, 4.0, 6.0, 8.0, 10.0,
Direction of Wind Vector (from upslope)	deg	0

Terrain

Slope Steepness	%	0

Run Options

Calculations are only for the direction of maximum spread.

Fireline intensity, flame length, and spread distance are always for the direction of the spread calculations.

Wind and spread directions are degrees clockwise from upslope.

Wind direction is the direction the wind is pushing the fire.

Output Variables

Flame Length (ft)

Direction of Maximum Spread (from upslope) (deg)

Maximum Wind Exceeded?

Notes

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Prescription Windows
Flame Length (ft)

1-h Moisture %	Midflame Wind Speed mi/h 2.0	4.0	6.0	8.0	10.0	12.0 >
3	3.8	6.1	8.4	10.6	12.8	14.9
5	3.4	5.5	7.5	9.5	11.4	13.2
7	3.2	5.1	7.0	8.9	10.7	12.4
9	3.0	4.8	6.6	8.3	10.0	11.7
11	2.6	4.2	5.8	7.3	8.8	10.2
13	1.9	3.1	4.2	5.3	6.4	7.4
15	0.1	0.1	0.1	0.1	0.1	0.1

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Prescription Windows
Flame Length (ft)

< 1-h Moisture %	Midflame Wind Speed mi/h 14.0
3	16.9
5	15.0
7	14.1
9	13.3
11	11.6
13	8.4
15	0.1

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Fireline Intensity (Btu/ft/s)

1-h Moisture %	Midflame Wind Speed mi/h 2.0	4.0	6.0	8.0	10.0	12.0 >
3	102	292	584	971	1447	2009
5	79	227	453	753	1122	1558
7	69	198	395	656	977	1357
9	60	172	344	571	852	1183
11	45	129	258	428	638	886
13	22	64	128	213	317	440
15	0	0	0	0	0	0

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Fireline Intensity (Btu/ft/s)

< 1-h Moisture %	Midflame Wind Speed mi/h 14.0
3	2655
5	2059
7	1794
9	1563
11	1171
13	582
15	0

It is obvious that most combinations of 1-hour fuel moisture and wind speeds will meet the stated burn objective. In a broad sense, the prescription window could be stated to include most combinations of 1-hour fuel moisture and midflame wind speed.

The important fact is that on burn day, you, the prescribed fire planner now Burn Boss, must make a defensible decision based upon current environmental conditions concerning whether to ignite the unit.

The next step requires that the prescribed fire planner determine appropriate temperature and relative humidity conditions which will produce desired 1-hour fuel moisture. In order to accomplish this, the fuel moisture tables within the field reference guide need to be used in reverse.
Since 1 Hour Fuel Moisture = Reference Fuel Moisture + Dead Fuel Moisture Content Correction

<u>and since</u>

Reference Fuel Moisture = f(temperature, relative humidity)

In order to determine temperature and relative humidity values which produce required 1-hour fuel moisture, the dead fuel moisture content correction has to be subtracted from the 1-hour fuel moisture to obtain the reference fuel moisture. The reference fuel moisture table (Table A) in the Field Reference Guide is then used to determine necessary temperature and relative humidity readings.

Given: Fuel Model 2 as described above.   Assume shading is less than 50%, slope is 0%, planned ignition time is between 1000 and 1200, and ignition is planned for some time during the month of June.

Find: Temperature and Relative Humidity ranges which will produce 1-hour fuel moisture of 7-9%.

Method: Determine dead fuel moisture content correction for June, 1000-1200, 0% slope, shaded fuels. Assume that weather observations are + or - 1000 ft of site location. Reference and Correction Factors for fuel moisture are found on pages 81-88.

Correction factors are 1% for 1000, and 0% for 1200. Using a worst case scenario to calculate reference fuel moisture, subtract 1% from the 1-hour fuel moisture of 7-9%. Reference fuel moisture becomes 6-8%.

Now find combinations of dry bulb temperatures and relative humidity which produce fuel moisture of 6-8%. From the reference fuel moisture table, at temperatures of 10-109 degrees and relative humidities of 35-64%, the reference fuel moisture is calculated at 6-8%. Not all combinations result in the correct moisture. Look at 70 degrees and 35%.

Within reason, most temperature/RH combinations between 10-109 degrees and 35-64% will produce 1 hour fuel moistures of 6-8%!

For planning purposes, a wide range of temperature/RH combinations may be used to determine appropriate fuel moistures. The planner needs to apply a professionally based knowledge of local conditions to the possible solutions to arrive at a reasonable range of expected temperature/RH conditions for the given time frame.

Two cautions: (1) If the range of conditions is too narrow, a really good burn day may be missed because according to the plan, you are out of prescription, and (2) using a wide range of temperature/RH combinations does **not** mean that all of them are in prescription.